












# Noble Elements Summary

Conveners: Jonathan Asaadi, Jen Raaf  
March 22, 2021  
CPAD 2021





# Excellent presentations in our parallel sessions!


## Thursday

<b>A Digital Tension Measurement Device for Multi-Wire Particle Detectors</b>	<i>Shion Kubota</i> 
<i>Stony Brook, NY</i>	11:00 - 11:20
<b>Measuring trace krypton for the LUX-ZEPLIN dark matter search</b>	<i>John Silk</i> 
<i>Stony Brook, NY</i>	11:20 - 11:40
<b>Modeling Impurity Concentrations in Liquid Argon Detectors</b>	<i>Yichen Li et al.</i> 
<i>Stony Brook, NY</i>	11:40 - 12:00
<b>Purity monitoring for ProtoDUNE-SP</b>	<i>Wenjie Wu</i> 
<i>Stony Brook, NY</i>	12:00 - 12:20
<b>Low-energy Monoenergetic Neutron Production with a DD-Neutron Source for sub-keV Nuclear Recoil Calibrations in the LUX and LZ Experiments</b>	<i>Will Taylor</i> 

<b>Scintillation and Optical Properties of the Low-Background Scintillator, PEN</b>	<i>Mrs Brennan Hackett</i> 
<i>Stony Brook, NY</i>	13:00 - 13:20
<b>Wavelength-Shifting Performance of Polyethylene Naphthalate Films in a Liquid Argon Environment</b>	<i>Ryan Dorrell</i> 
<i>Stony Brook, NY</i>	13:20 - 13:40
<b>Light production in liquid and gaseous argon</b>	<i>Dr Carlos Ourivio Escobar</i> 
<i>Stony Brook, NY</i>	13:40 - 14:00
<b>Improving the Proportional Scintillation Signal of Liquid Argon by Xenon Doping</b>	<i>Ethan Bernard</i> 
<i>Stony Brook, NY</i>	14:00 - 14:20
<b>Modeling xenon and argon physics with the Noble Element Simulation Technique (NEST)</b>	<i>Vetri Velan</i> 
<i>Stony Brook, NY</i>	14:20 - 14:40
<b>Building low background kton-scale liquid argon time projection chambers for physics discovery</b>	<i>Christopher Jackson</i> 
<i>Stony Brook, NY</i>	14:40 - 15:00

## Friday

<b>Augmented Signal Processing in Liquid Argon Time Projection Chambers with a Deep Neural Network</b>	<i>Haiwang Yu</i> 
<i>Stony Brook, NY</i>	11:00 - 11:20
<b>Using Photo-converting Dopants to Improve Large LArTPC Performance</b>	<i>Joseph Zennaro</i> 
<i>Stony Brook, NY</i>	11:20 - 11:40
<b>QPIX, a novel pixel technology for very large noble element detectors</b>	<i>Austin McDonald</i> 
<i>Stony Brook, NY</i>	11:40 - 12:00
<b>High pressure gas TPC technology for neutrinoless double beta decay searches: The NEXT program</b>	<i>Jonathan Haefner</i> 
<i>Stony Brook, NY</i>	12:00 - 12:20
<b>Metastable Liquids: Breakthrough Technologies for Dark Matter and Neutrinos</b>	<i>Prof. Matthew Szydagis</i>
<i>Stony Brook, NY</i>	12:20 - 12:40

<b>Designing and building a pair of scintillating bubble chambers for WIMPs and reactor CEvNS</b>	<i>Rocco Coppejans</i> 
<i>Stony Brook, NY</i>	13:00 - 13:25
<b>HeRALD - light dark matter search with superfluid Helium-4</b>	<i>Junsong Lin</i>
<i>Stony Brook, NY</i>	13:25 - 13:50

# 2019 DOE Basic Research Needs Study

## Noble Elements Priority Research Directions

Priority Research Direction (PRD)	Technical Requirement (TR)
PRD 4: Enhance and combine existing modalities to increase signal-to-noise and reconstruction fidelity PRD 5: Develop new modalities for signal detection	TR 1.3.3, 2.1, 2.4, 2.5, 2.7, 2.9, 3.3, 3.6, 3.9, 3.12, 3.13, 3.15, 3.17, 3.19
PRD 6: Improve the understanding of detector microphysics and characterization to increase signal-to-noise and reconstruction fidelity	TR 2.8, 2.9, 3.3, 3.6, 3.9, 3.12, 3.13, 3.15, 3.17, 3.19
PRD 25: Advance material purification and assay methods to increase sensitivity	TR 2.3, 3.1, 3.4, 3.7, 3.10
PRD 26: Addressing challenges in scaling technologies	TR 2.1, 2.3, 2.4, 2.7, 2.9, 3.2, 3.5, 3.8, 3.11, 3.14, 3.16, 3.18, 3.20

Table 15: Table mapping Priority Research Directions to Technical Requirements.

# PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

J. Zennaro

## Photon Conversion

- These chemicals work by having an ionization energy near the scintillation photon energy

- Convert scintillation light into ionization charge

- Literature has explored many potential choices (\*), the most commonly used:

- Tetramethylgermane (**TMG**),  $(\text{CH}_3)_4\text{Ge}$
- Trimethylamine (**TMA**),  $\text{N}(\text{CH}_3)_3$
- Triethylamine (**TEA**),  $\text{N}(\text{CH}_2\text{CH}_3)_3$

- These chemicals have a long track record of demonstrations in the literature starting back in the early 1970s**

### Scintillation $\gamma$ Energy

**LAr** 9.6 eV

**LAr+Xe** 7.0-9.6 eV

### Ionization Energies

**TMG** 9.2 eV

**TMA** 7.8 eV

**TEA** 7.5 eV

(In LAr these drop by  $\sim 0.7$  eV)

(\*) D.F. Anderson, Nucl. Instr. and Meth. A 242 (1986) 255  
J. Zennaro, Fermilab

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## Other Benefits of Xenon-Doping

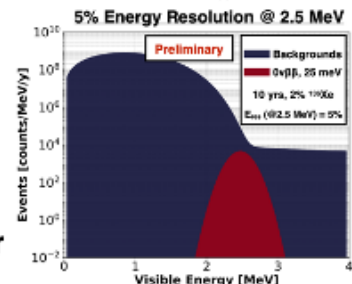
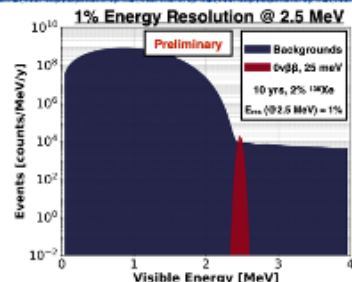
- On top of modifying the detector's performance  $^{136}\text{Xe}$  is also a  $0\nu\beta\beta$  candidate isotope

- Doping with  $^{136}\text{Xe}$  could enable a 100-ton scale search for  $0\nu\beta\beta$

- Concept:** Dope DUNE FD module LAr with 2%  $^{136}\text{Xe}$  ( $Q_{\beta\beta} = 2.5$  MeV)

- Enabling a **>300-ton** mass of xenon to sit within a 2 m fully active LAr buffer, eliminating most surface backgrounds
- Additional background suppression comes via multisite tagging

- To enable such a search one needs to utilize  $^{42}\text{Ar}$  depleted LAr**



J. Zennaro, Fermilab

Publication pending, A. Mastbaum, F. Psihas, J. Zennaro

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# PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

E. Bernard

## S2 Light Measurement Improvement by Addition of Xenon To Argon

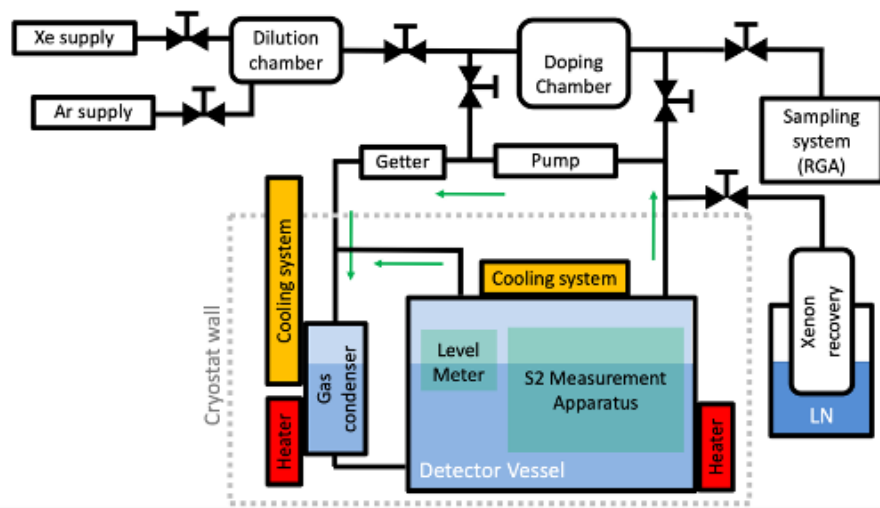
Improvements in light production and sensing of the S2 pulse

- Xe – containing excimers emit at longer wavelengths that are more efficiently measured.
- Xe – containing excimers emit their light faster, shortening pulse duration.
- Xe\* has a lower threshold for excitation → more excitations per drift electron

Improvements in ionization yield of the liquid (speculative)

- Xenon has a lower ionization energy than argon → more electrons per unit deposited energy
- Xenon may be ionized by the Penning process  $\text{Ar}^* + \text{Xe} \rightarrow \text{Ar} + \text{Xe}^+ + e^-$

## Xenon-Doped Argon Circulation Scheme



Lawrence Livermore National Laboratory  
LLNL-PRES-015515

NLSA 25

# PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

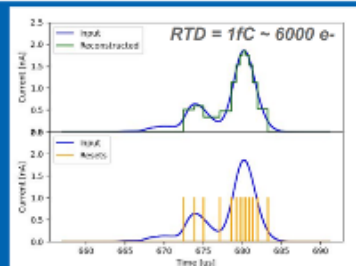
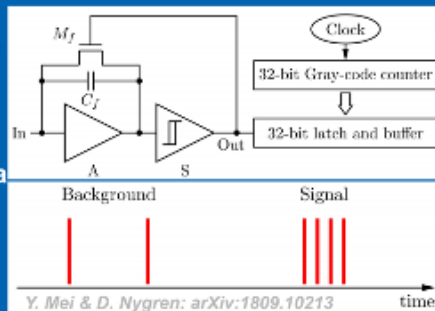
A.D. McDonald

## Q-Pix work in the context of DUNE (Supernova)

Compressing a full 10s of background in an APA with a single supernova neutrino (no cuts) on to the pixel plane the

### An unorthodox solution: Q-Pix

- The Q-Pix pixel readout follows the “electronic principle of least action”
  - Don't do anything unless there is something to do
- Offers an innovation in signal capture with a new approach in measuring **time-to-charge: ( $\Delta Q$ )**
  - Keeps the detailed waveforms of the LArTPC
- Take the **difference** between **sequential** resets
  - Reset Time Difference =  $RTD = \Delta Q$
- RTD's measure the **instantaneous current** and captures the waveform
  - Small average current (background) = **Large RTD**
    - Background from  $^{39}\text{Ar} \sim 100 \text{ aA}$
  - Large average current (signal) = **Small RTD**
    - Typical minimum ionizing track  $\sim 1.5 \text{ nA}$



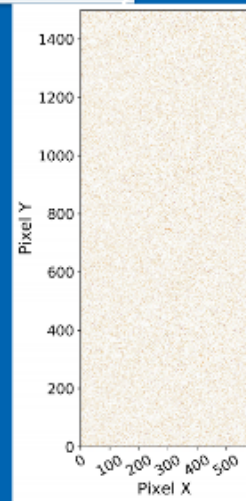
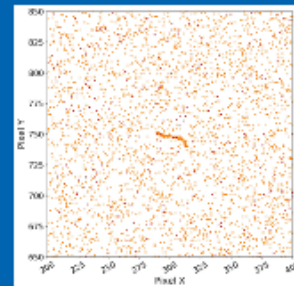
ly visible.

require a trigger  
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system will  
&D ongoing)

f readout

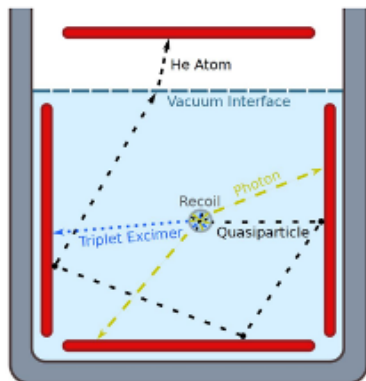


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# PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

J. Lin

## Helium Roton Apparatus for Light Dark matter (HeRALD)

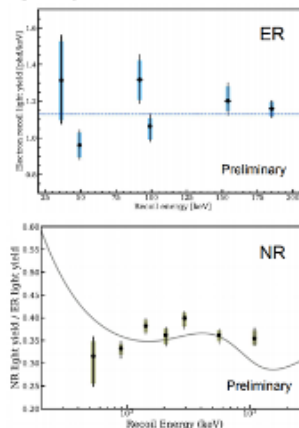


- Operated at mK
- Calorimeters with TES readout
  - submerged in liquid
    - Detect **UV photons, triplet molecules and IR photons**
  - suspended in vacuum
    - Detect **UV photons, IR photons and He atoms** (evaporated from quasiparticle)

HeRALD concept and sensitivity paper  
[PhysRevD.100.032007](#)

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## Light yield measurement of superfluid He-4

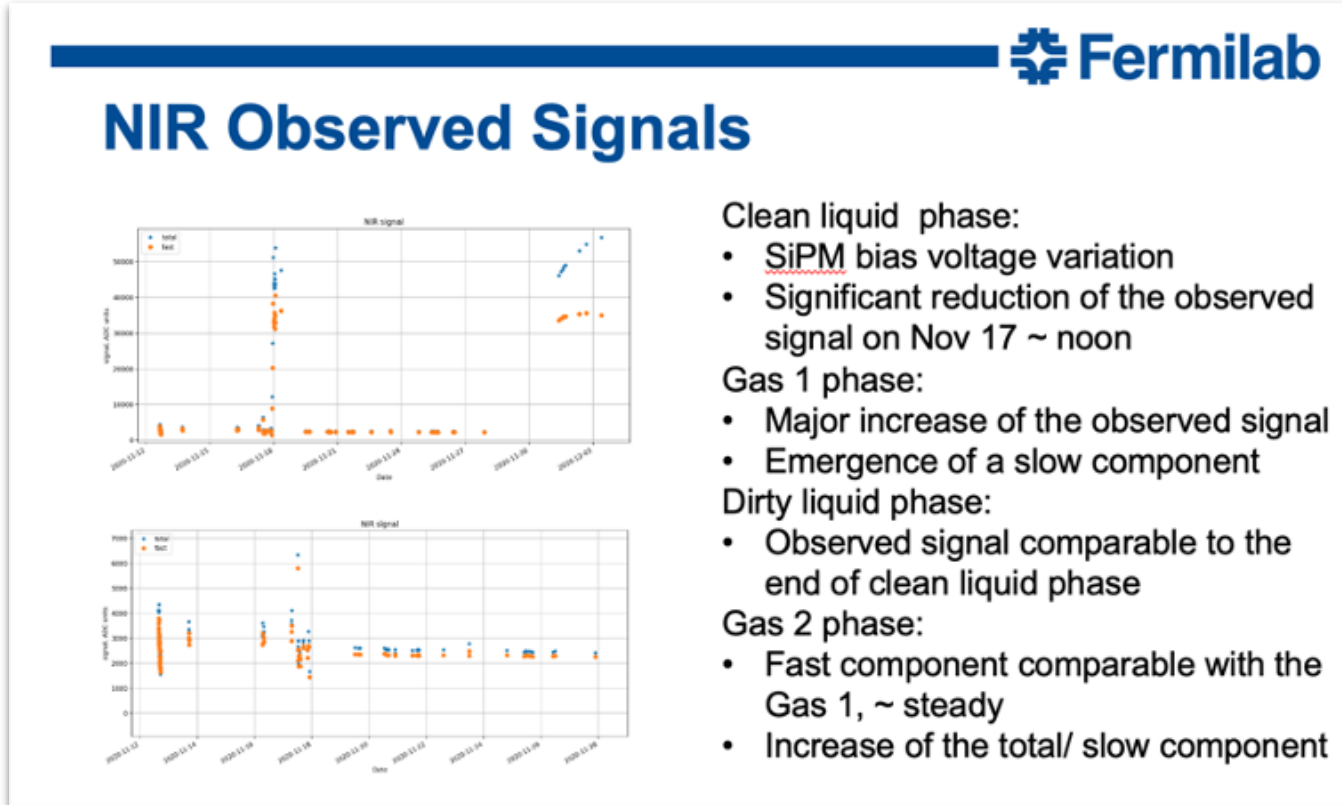


- First measurement in tens of keV
- ER yield relatively flat (as expected)
- NR yield agrees pre-defined model
- Working on lower energy ( $\sim$  keV)
  - ER: Compton scattering from Co-57 source
  - NR: SbBe with iron filter

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# PRD 5: Develop new modalities for signal detection

C. Escobar





# PRD 5: Develop new modalities for signal detection

R. Coppejans

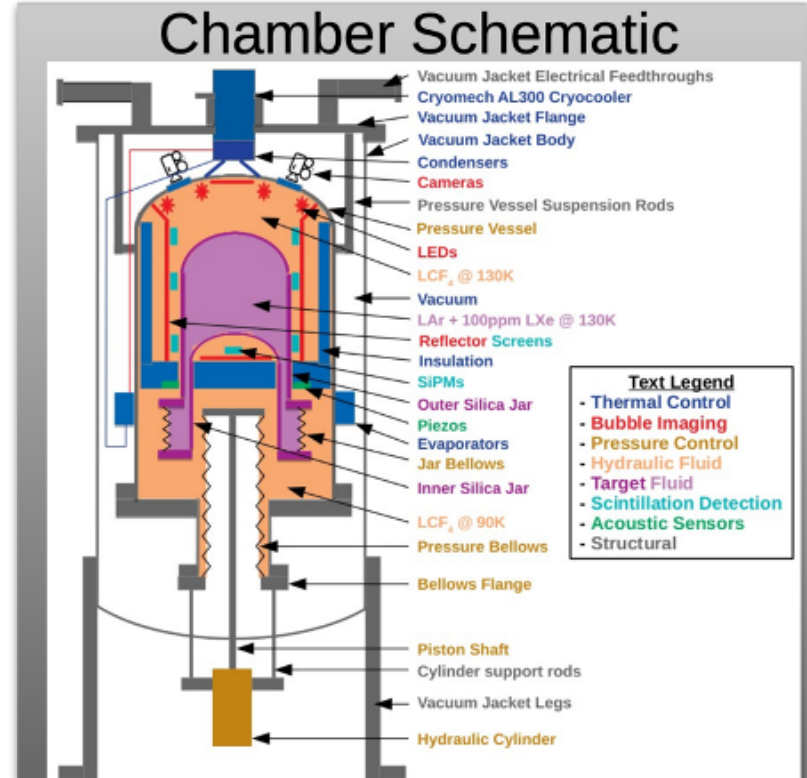
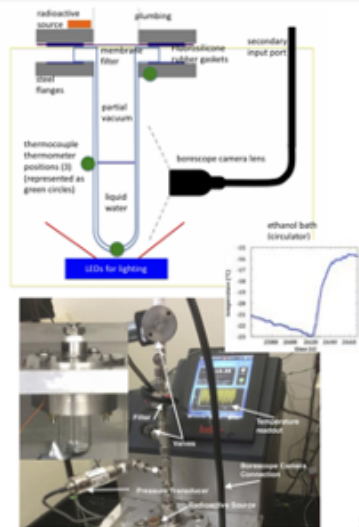
Metastable liquids: phase transition detectors

- Snowball Chamber (super-cooled water)
- Scintillating Bubble Chamber (super-heated LAr-LXe)

M. Szydagis

## The Basics: How This Works

- A pure liquid can be made “metastable,” making it sensitive to incoming particles
  - For supercooling, this involves dropping temperature below freezing sans freezing, relying on a sufficiently clean, smooth container
- Controlling the temperature and/or pressure allows one to control the thresholds in both energy as well as  $dE/dx$  or critical radius for nucleation, enabling signal vs. background discrimination (e.g., betas and gamma-rays)
  - Lower temperature means both thresholds lower, in supercooling. Like bubble chamber, but in reverse!
- Have only done water so far. What does it have to do with noble elements? - Could do Xe or Ar to capitalize on scintillation for  $E$



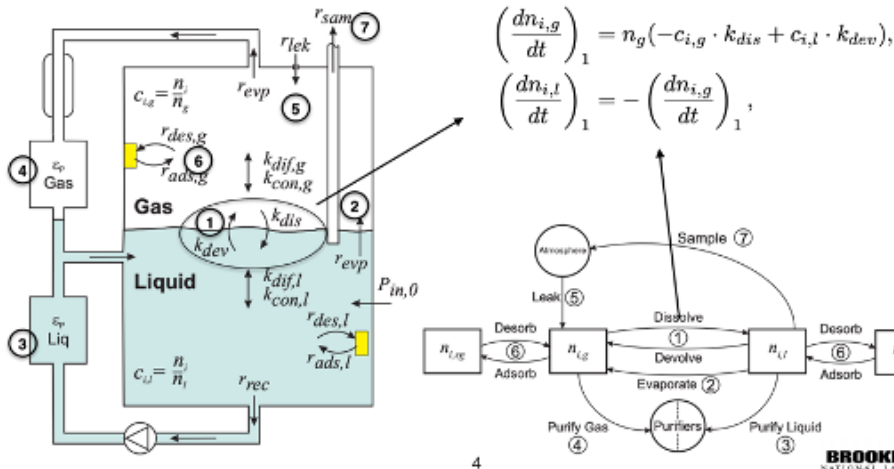
# PRD 6: Improve the understanding of detector microphysics and characterization to increase S:N and reconstruction fidelity

Y. Li

## Model Description

arXiv:2009.10906

- A quantitative kinetic model of impurity distribution is constructed
- Two species (Ar and impurity) in four places (gas, liquid, contact surfaces with gas/liquid)
- Each process is described by an ordinary differential equation
- The entire model is the sum of 7 processes



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BROOKHAVEN  
NATIONAL LABORATORY

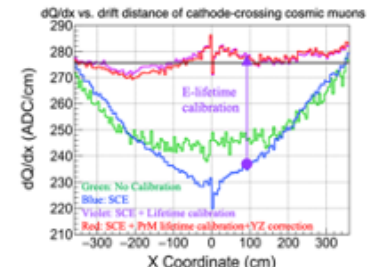
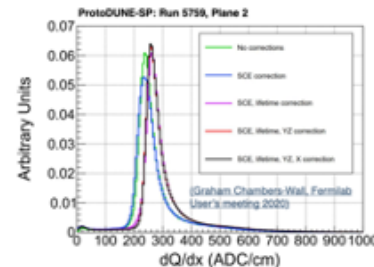
2021 March 22

J. Raaf

W. Wu

## Calibration scheme of ProtoDUNE-SP

- Electron lifetime calibrated with purity monitors.
- Space charge effect corrected with cosmic rays.
- Position calibration based on cosmic rays.
- Absolute energy calibration: stopping muons in cosmic rays.
- Other calibration methods under development: Ar39, neutron source, laser, radioactive source.



- Charge resolution improved
- Charge attenuation and non-uniformity on TPC signal are corrected

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2021.3.18

Wenjie Wu | Purity monitoring for ProtoDUNE-SP

UCIRVINE DUNE

CPAD 2021

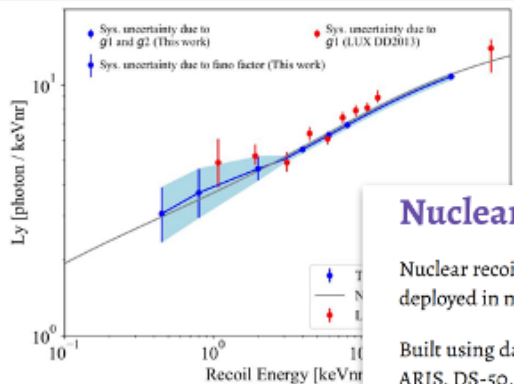
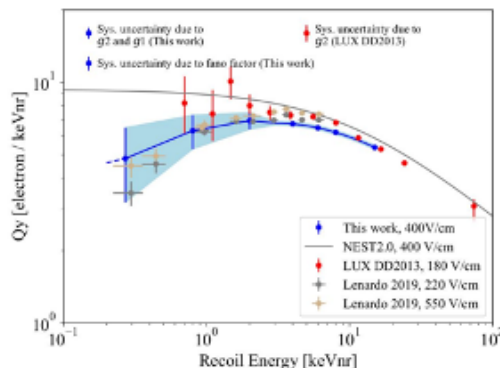
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# PRD 6: Improve the understanding of detector microphysics and characterization to increase S:N and reconstruction fidelity

W. Taylor

## LUX DD Calibration Results

- New results from LUX2016 DD data push  $Q_y$  and  $Ly$  measurements even lower in energy
- 0.27 keVnr -  $Q_y$
- 0.45 keVnr -  $Ly$



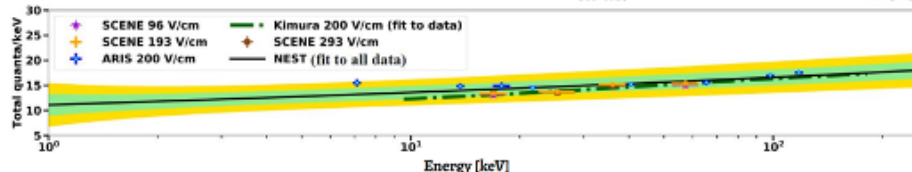
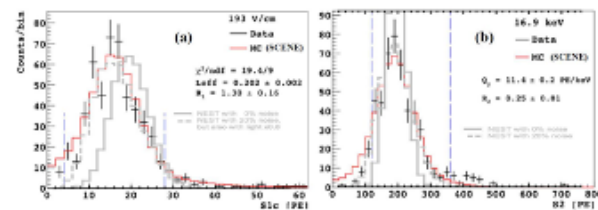
- New results obtained through the combined comprehensive signal model, NEST predict restrictive geometric cuts to improve event combination with a pulsed DD neutron source
- See [CPAD 2018 talk](#) for additional information

Figures from [Dongqing Huang's PhD thesis](#)  
Publication forthcoming

## Nuclear Recoils in Argon

Nuclear recoil argon model now deployed in main NEST code

Built using data from SCENE, ARIS, DS-50, Joshi, Aprile, Lippincott, Kimura, Doke, etc.



March 18, 2021

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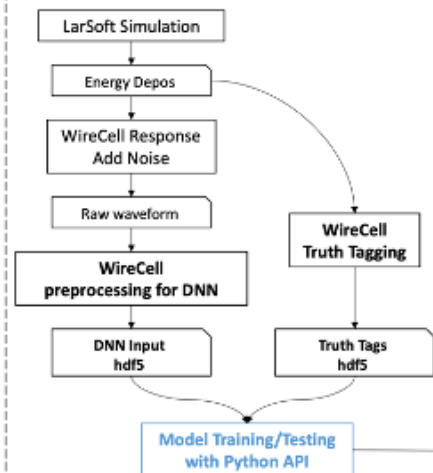
V. Velan

# PRD 6: Improve the understanding of detector microphysics and characterization to increase S:N and reconstruction fidelity

H. Yu

## Deep-Learning in Wire-Cell Toolkit

### Training workflow

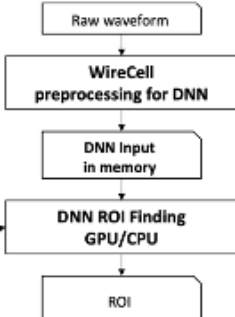


Established initial machinery for Deep-Learning in Wire-Cell Toolkit

<https://github.com/WireCell/wire-cell-toolkit>

- Data preparing in LarSoft/Wire-Cell
- Training with python
- Production with C++

### Production workflow



Reference SP

ProtoDUNE-SP Data  
run: 5145  
subRun: 1  
event: 26945  
V plane

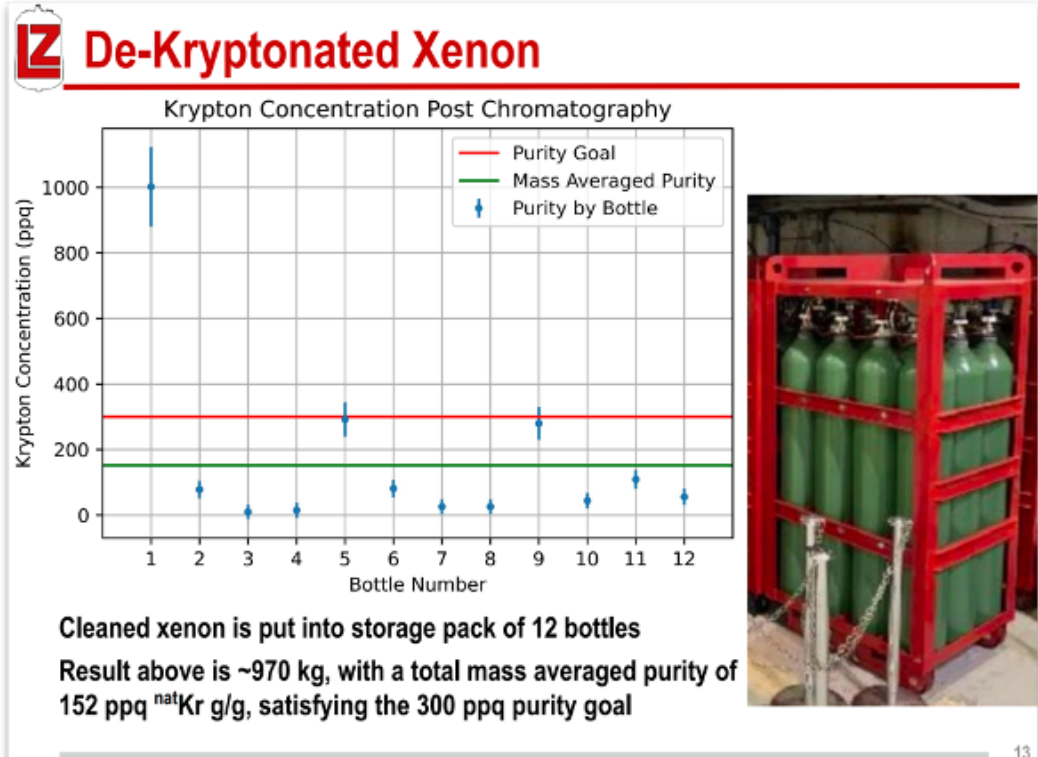
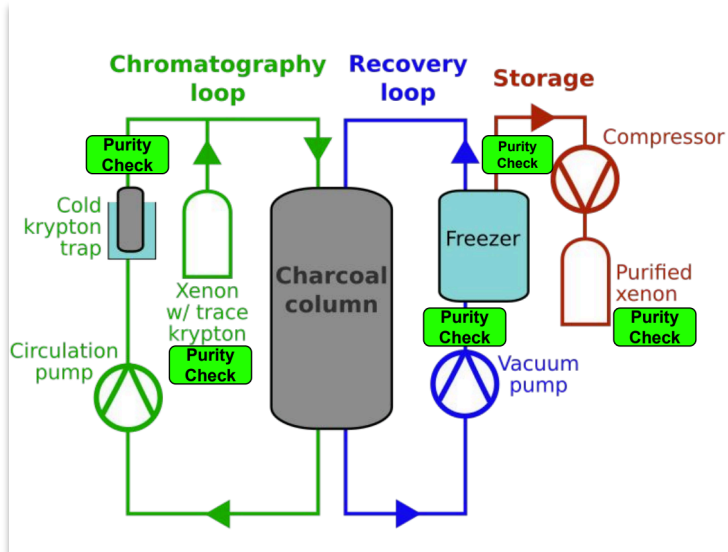
ProtoDUNE: how and why  
L. Manenti: X02.00001  
and other ProtoDUNE Talks

DNN-SP

ProtoDUNE-SP Data  
run: 5145  
subRun: 1  
event: 26945  
V plane

# PRD 25: Advance material purification and assay methods to increase sensitivity

J. Silk



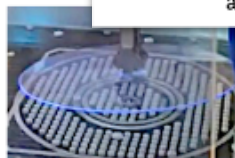
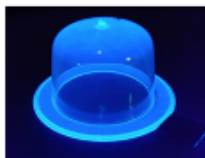
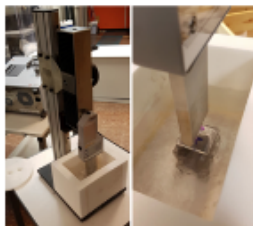
# PRD 25: Advance material purification and assay methods to increase sensitivity

R. Dorrill

B. Hackett

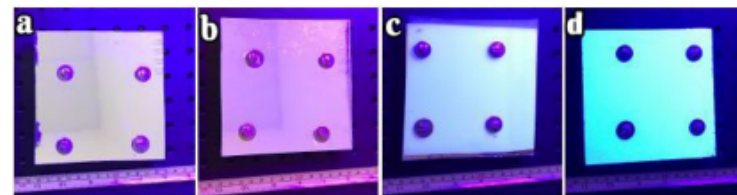
## Conclusion

- PEN is a novel scintillating material
- It has potential applications in both noble detectors and low background experiments
- PEN has a demonstrated structural stability
  - Yield strength higher than copper at cryogenic temperatures
- Injection molding can prevent crystalline structures forming in PEN
  - Improved optical clarity
  - Alternative geometries other than commercially available films



## Samples Tested

Data Sample	Origin	Trade Name	Thickness	Properties
PEN01	Piedmont	Teonex Q65FA	0.125m	Ultra-clear
PEN02	ORNL	Teonex TN-8065S	1.5mm	Low crystallinity, clear
PEN03	Millipore Sigma	Teonex Q53	0.125mm	Biaxially oriented, hazy
PEN04	Goodfellow	Teonex Q53	0.125mm	Biaxially oriented, hazy
TPB	Manchester Univ.	-	0.003mm	Evaporatively deposited
Bare	-	-	-	No WLS layer applied



The bare reflector (a), PEN01 (b), PEN04(c), and TPB (d). Note PEN04's hazy appearance compared to PEN01.

Alternative WLS materials with low radioactivity

Also relevant for PRD #4!



# PRD 25: Advance material purification and assay methods to increase sensitivity

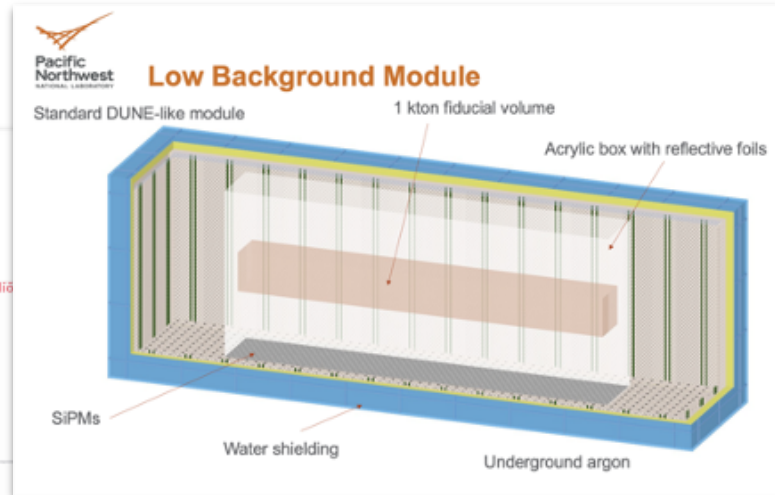
C. Jackson



## How to build this?

- Assay management
  - Radiopurity.org based assay manager
    - ✓ Interface for non-experts to request assays
    - ✓ Guided input of relevant information
    - ✓ Low background experts guide distribution of assay work
    - ✓ Tracks samples and locations
- Assay results and triage
  - Background Explorer
    - ✓ Toolkit for modeling radioactive backgrounds
    - ✓ Rapid evaluation of effect of new assay measurement on background tables
    - ✓ Originally developed for SuperCDMS by Ben Loer
    - ✓ <https://github.com/bloer/bgexplorer-demo>

The image shows two parts of the workflow. The top part is a screenshot of the 'Assay Request' form on the Radiopurity.org website, which includes fields for sample information, detector details, and measurement parameters. The bottom part is a screenshot of the 'Background Explorer' tool, showing a list of components that can be modeled, such as DUNE\_SIP, Argon, WPM, CPA, Crystal, I-beams, Argon skin, Foam insulation, Wood insulation, and Cables.



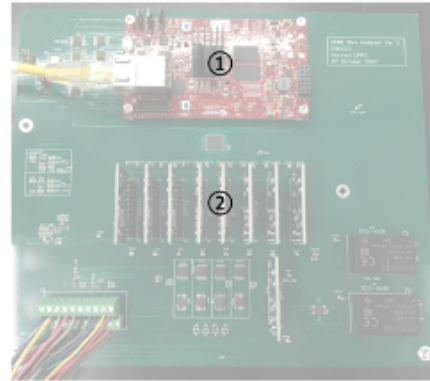
# PRD 26: Addressing challenges in scaling technologies

New techniques for measuring wire tensions in future large TPCs...

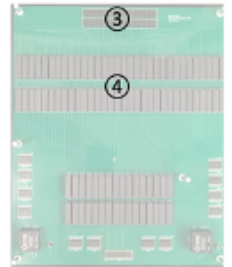
S. Kubota



## Sneak peek inside the Digital Wire Analyzer



- ① FPGA creates square wave
- ② Bandpass filter converts a square wave to a sine wave
- ③ A sine wave will be sent out to the selected wires by Relay Boards
- ④ Signal in the test wires are detected/received



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A Novel Electrical Method to Measure Wire Tensions for Time Projection Chambers  
Nucl.Instrum.Meth.A 915 (2019) 75-81



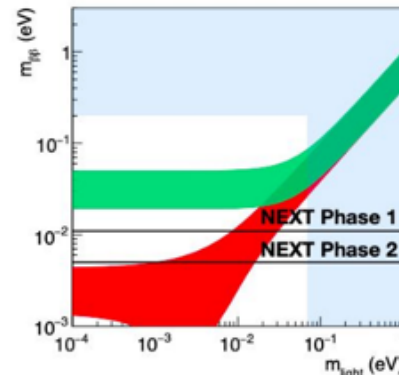
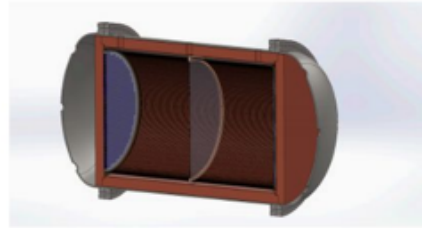
# PRD 26: Addressing challenges in scaling technologies

R&D to enable to ton-scale OnuBB

J. Haefner

## NEXT-Ton: basics

- Require a larger detector (10x mass of N100)
- With larger size, some challenges:
  - Larger volume to calibrate
  - Longer drift distance
- Must maintain:
  - excellent resolution
  - topological rejection power



### Two approaches developed in parallel:

- Phase 1, High Definition: incremental approach, using/improving existing technology.
- Phase 2, Barium Tagging: based on disruptive new concept (SMFI Ba++ tagging).

### Phased approach

- ~1 ton of  $^{136}\text{Xe}$  introduced per phase.
- Ultra pure materials. SiPMs as the only sensor.

### Phase 1:

- Improves topological signature, improves energy resolution
- Reduces radioactive budget (no PMTs)
- Energy plane made of large area SiPMs (design similar to that of Dark Side)
- Potential to reduce SiPM dark count by cooling detector
- $2.6 \times 10^{-6}$  cts / keV · kg · year total background rate

### Phase 2:

- Tracking and energy measured in anode.
- Cathode implements Barium Tagging System
- Virtually background free

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# Closing Remarks

- ❑ Lots of interesting results and advances in techniques, tools, and instrumentation
- ❑ Focus: how to do things at larger scale with higher sensitivity
- ❑ Looking forward to see how much farther we will be able to advance by the next CPAD!

*Thank you to all the session speakers for their excellent talks!*